UNIVERSITY OF ESWATINI
FACULTY OF SCIENCE & ENGINEERING
DEPARTMENT OF PHYSICS
SEMESTER I, RE-SIT EXAMINATION: 2019/2020

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TITLE OF PAPER: NUCLEAR PHYSICS

COURSE CODE: PHY441/P441

TOTAL TIME ALLOWED: THREE(3) HOURS

INSTRUCTIONS:

- THIS EXAMINATION HAS FIVE (5) QUESTIONS. ANSWER ANY FOUR (4).
- EACH QUESTION CARRIES 25 POINTS.
- POINTS FOR DIFFERENT SECTIONS ARE INDICATED IN THE RIGHT-HAND MARGIN.

THE PAPER HAS 4 PAGES, INCLUDING THIS PAGE. TWO (2) ADDITIONAL PAGES OF USEFUL DATA HAVE BEEN APPENDED AT THE END.

DO NOT OPEN THIS PAGE UNTIL PERMISSION HAS BEEN GIVEN BY THE INVIGILATOR

Question 1

(a) With the aid of a diagram, describe the principle of operation of a mass spectrometer.

[10 marks]

(b) Singly charged chlorine ions are accelerated through a fixed potential difference and then caused to travel in circular paths by means of a uniform field of magnetic induction of 1000 Gauss. What increase in induction is necessary to cause a mass 37 ion to follow the path previously taken by a mass 35 ion?

[15 marks]

Question 2

(a) Thermal neutrons have speed v at temperature T = 300K and kinetic energy $\frac{m_n v^2}{2} = \frac{3kT}{2}$. Calculate the de Broglie wavelength of the thermal neutrons. Can these neutrons be diffracted by cystals?

[10 marks]

(b) Given a proposed wave-function for the hydrogen atom:

$$\psi(r) = A \cdot e^{\frac{-r}{a_0}},$$

where $a_0 = 53$ pm.

(i) Normalize the wave-function.

[5 marks]

Hint:

$$\int_0^\infty x^n e^{-ax} dx = \frac{n!}{a^{n+1}}$$

(ii) Calculate the probability that the electron will be found within a sphere of radius 1.0 pm centered on the nucleus.

[5 marks]

(iii) Calculate the average value (expectation value) of the distance of the electron from the nucleus. Take $dv = d\tau = r^2 sin\theta dr d\theta d\phi$.

[5 marks]

Question 3

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(a) A positron and an electron with negligible kinetic energy meet and annihilate one another, producing two γ-rays of equal energy. What is the wavelength of these γ-rays?

[10 marks]

(b) Classify the following transitions (the spin parity, J^P, of the nuclear states are given in brackets):

(i) $^{14}O \rightarrow ^{14}N^* + e^+ + \nu (0^+ \rightarrow 0^+)$

[5 marks]

(ii) $^{6}He \rightarrow ^{6}Li + e^- + \nu (0^+ \rightarrow 1^+)$

[5 marks]

(c) Why is the following transition called a super-allowed transition?

$$^{17}F \rightarrow ^{17}O + e^- + \nu \left(\frac{5}{2}^+ \rightarrow \frac{5}{2}^+ \right)$$

[5 marks]

Question 4

(a) The disintegration rate of a radioactive source was measured at intervals of four minutes. The rate was found to be (in arbitrary units) 18.59, 13.27, 10.68, 9.34, 8.55, 8.03, 7.63, 7.30, 6.99, 6.71, and 6.44. Assuming that the source contained only one or two types of radio-nuclides, calculate the half lives involved.

[15 marks]

(b) Radium being a member of the uranium series occurs in uranium ores. If the half lives of uranium and radium are respectively 4.5 x 10^9 and 1,620 years, calculate the relative proportions of these elements in a uranium ore, which has attained equilibrium and from which none of the radioactive products have escaped.

[10 marks]

Question 5

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(a) List the four (4) fundamental forces of the standard model. For each force, give both the mediating particle(s) and a relative range of the force.

[12 marks]

(b) β-decay of the neutron to a proton is mediated by the emission of a W^- boson. In this interaction one of the d quarks is converted into a u quark. Draw a fully labelled first order diagram depicting this process ($n \rightarrow p^+ + e^- + \bar{\nu}_e$).

[5 marks]

(c) Why wouldn't the following reactions occur as strong interactions?

(i) $\pi^- + p \rightarrow K^- + \Sigma^+$

[4 marks]

(ii) $d + d \rightarrow^4 He + \pi^0$

[4 marks]

!!!!!!!!THIS IS THE END OF THE EXAMINATION PAPER!!!!!!!

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Useful Data:

1 unified mass unit (u) $= 1.6605 \times 10^{-27}$ kg $= 931.5$ MeV/c^2

Planck's constant $h = 6.63 \times 10^{-34}$ Js

Boltzmann's constant $k = 1.38 \times 10^{-23}$ J/K

Avogadro's number $N_A = 6.022 \times 10^{23}$ mol^{-1}

Speed of light (vacuum) $c = 3.0 \times 10^8$ m/s

electron mass $m_e = 9.11 \times 10^{-31}$ kg $= 5.4858 \times 10^{-4}$ u $= 0.511$ MeV/c^2

neutron mass $m_n = 1.6749 \times 10^{-27}$ kg $= 1.008665$ u $= 939.573$ MeV/c^2

proton mass $m_p = 1.6726 \times 10^{-27}$ kg $= 1.0072765$ u $= 938.280$ MeV/c^2

1year $= 3.156 \times 10^7$ s

nuclear radius, $R \approx r_0 A^{1/3}$, where $r_0 = 1.2$ fm

fine structure constant, $\alpha = \frac{e^2}{4\pi\epsilon_0 \hbar c} = \frac{1}{137}$

$\hbar c = 197$ MeVfm

The table of nuclear properties is provided in the next page.

Nuclide	Z	A	Atomic mass (u)	I^π	Abundance or Half life
H	1	1	1.007825	$1/2^+$	99.985%
He	2	4	4.002603	0^+	99.99986%
Li	3	7	7.016003	$3/2^-$	92.5%
Be	4	11	11.021658	$1/2^+$	13.8 s (β^-)
B	5	11	11.009305	$3/2^-$	80.2%
C	6	12	12.00000	0^+	99.89%
N	7	15	15.00109	$1/2^-$	0.366%
N	7	18	18.014081	1^-	0.63 s
O	8	15	15.003065	$1/2^-$	122 s
O	8	16	15.994915	0^+	99.76%
O	8	18	17.999160	0^+	0.204%
F	9	18	18.000937	1^+	110.0 min
Ne	10	20	19.992436	0^+	90.51%
Ne	10	22	21.991383	0^+	9.33%
Na	11	22	21.994434	3^+	2.60 yrs
Mg	12	21	21.000574	0^+	3.86 s
Al	13	27	26.981539	$5/2^+$	100.0%
Si	14	30	29.973770	0^+	3.10%
Si	14	32	31.974148	0^+	105 yrs
P	15	30	29.978307	1^+	2.50 min
P	15	32	31.971725	1^+	14.3 days
S	16	32	31.972071	0^+	95.02%
Cl	17	37	36.965903	$3/2^+$	24.23%
Ar	18	37	36.966776	$3/2^+$	35.0 days
K	19	37	36.973377	$3/2^-$	1.23 s
Ca	20	43	42.958766	$7/2^-$	0.135%
Ca	20	47	46.954543	$7/2^-$	4.54 days (β^-)
Sc	21	47	46.952409	$7/2^-$	3.35 days (β^-)
Fe	26	56	55.934439	0^+	91.8%
Fe	26	60	59.934078	0^+	1.5 Myrs
Co	27	60	59.933820	5^+	5.27 yrs
Ni	28	60	59.930788	0^+	26.1%
Ni	28	64	63.927968	0^+	0.91%
Ni	28	65	64.930086	$5/2^-$	2.52 hrs (β^-)
Cu	29	63	62.929599	$3/2^-$	69.2%
Cu	29	64	63.929800	1^+	12.7 hrs
Cu	29	65	64.927793	$3/2^+$	30.8%
Zn	30	64	63.929145	0^+	48.6%
Ru	44	104	103.905424	0^+	18.7%
Ru	44	105	104.907744	$3/2^+$	4.44 hrs (β^-)
Pd	46	105	104.905079	$5/2^+$	22.2%
Cs	55	137	136.907073	$7/2^+$	30.2 yrs (β^-)
Ba	56	137	136.905812	$3/2^+$	11.2%
Tl	81	203	202.972320	$1/2^+$	29.5%
Os	76	191	190.960920	$9/2^-$	15.4 days (β^-)
Ir	77	191	190.960584	$3/2^+$	37.3%
Au	79	199	198.968254	$3/2^+$	16.8%